THE POTASSIUM–ARGON LASER EXPERIMENT (KArLE): DESIGN CONCEPTS.

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Introduction: The absolute ages of geologic events are fundamental information for understanding the timing and duration of surface processes on planetary bodies. Absolute ages can place a planet's history in the context of the solar system evolution. For example, "when was Mars warm and wet?" is one of the key questions of planetary science. If Mars was warm and wet until 3.7 billion years ago, for instance, it suggests that Mars was still warm and wet when life appeared on Earth. Mars history has been discussed so far based on crater chronology, but the current constraints for Martian chronology models come from the cratering history of the Moon [1]. Moreover, the lunar chronology model itself is fraught with uncertainty because our understanding of lunar chronology is constrained only in a few time periods and itself needs further investigation relating crater-counting ages to absolute ages [2].

Although sample return missions would provide highly accurate radiometric ages of returned samples, they are very expensive and technically challenging. In situ geochronology is highly valuable because they would have larger number of mission opportunities and the capability of iterative measurements for multiple rocks from multiple geologic units. The capability of flight instruments to perform in situ dating is required in the NASA Planetary Science Decadal Survey and the NASA Technology Roadmap. Beagle 2 is the only mission launched to date with the explicit aim to perform in situ potassium–argon (K–Ar) dating [3], but it did not happen because of the communication failure to the spacecraft. The first in situ K–Ar dating on Mars, using SAM and APXS measurements on the Cumberland mudstone [4], yielded an age of 4.21 ± 0.35 Ga and validated the idea of K–Ar dating on other planets. However, the Curiosity method is not purpose-built for dating and requires many assumptions that degrade its accuracy. To obtain more accurate and meaningful ages, multiple groups are developing dedicated in situ dating instruments [5–8].

KArLE methodology: KArLE measures the K–Ar ages of planetary samples using currently available, flight-proven instruments, in addition to providing the original analyses of the instrument. KArLE measures K using laser-induced breakdown spectroscopy (LIBS), measures the Ar liberated by the laser ablation using mass spectrometry (MS), and relates K and Ar by measuring the volume of the ablated pit using optical imaging. Note that analyzing the elemental and volatile compositions of the sample, as well as imaging

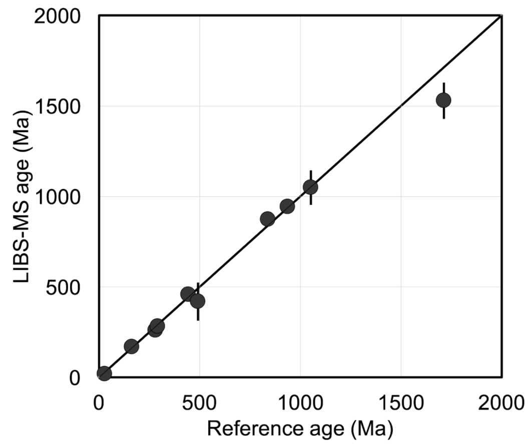

Fig. 1 Compiled K–Ar dating results published from multiple labs [5–8]. The K–Ar ages measured using the LIBS-MS methodology are shown against of the reference ages of the rocks used in each study.

the sample texture, are common to most planetary surface missions; in fact, LIBS, MS, and microimaging instruments were aboard Curiosity as ChemCam, SAM, and MAHLI, respectively. KArLE would use these flight-heritage components to reduce the cost, time, and risk of hardware development.

The capability of targeted analysis using a focused laser beam is another advantage of KArLE. A conventional whole-rock measurement yields an average K–Ar age (i.e., the combination of K and ^{40}Ar contents of a sample) determined using assumptions about the isotopic ratio ^{40}Ar/^{36}Ar or the concentration of trapped ^{40}Ar. However, these assumptions are not always valid for planetary materials [9]. In contrast, laser microanalysis yields multiple data points on minerals with different K concentrations within a single rock sample. This capability enables us to obtain an accurate isochron age of the sample and resolve the contribution of trapped ^{40}Ar [6]. Multiple data points from a single sample also allow a statistical analysis of the age data within the sample, which may be used for assessing the degree of mixing and/or resetting of the K–Ar age. In addition, the K–Ar age of a sample with a very low bulk K content may be measured by targeting small K-rich phases, which are otherwise diluted by more abundant K-poor minerals.

We have previously reported experimental results confirming the KArLE methodology [5, 6]. Data from multiple labs suggest that KArLE can determine the

age of geologic samples with an overall accuracy and precision of <100 Myr (Fig. 1), sufficient to address a wide range of fundamental questions in planetary science.

Conceptual designs of KArLE: We have designed several flight concepts for implementation of the KArLE experiment. Because KArLE relies on measurement of the ^{40}Ar extracted by the LIBS laser ablation, the ablation needs to occur within an enclosed chamber that does not allow sample gases to escape (or atmosphere to enter). Moreover, a sample handling system must be able to introduce a rock sample for multiple KArLE laser spot analyses. These two functions may be performed in multiple ways. One example is the Curiosity-like configuration (Fig. 2a) for a rover or lander. This configuration pursues a synergistic situation by taking advantage of a mast-mounted LIBS and body-mounted mass spectrometer that would be able to independently interrogate the environment. It is also possible to package the instrument components in a compact volume so that it is optimized for analysis inside the spacecraft body (Fig. 2b) [10]. The choice of the configuration depends on the particular mission design.

The KArLE experiment is flexible to the exact sampling system used by a spacecraft; a sample might be a rough, natural rock such as a pebble, a prepared sample such as a cut face, or a core sample from a drill. However, all flight concepts require the addition of a mechanically simple sample handling system (SHS). The SHS must be capable of ingesting a sample, achieving a vacuum seal, and enabling the measurements to be performed on the enclosed sample. Figure 3 illustrates a candidate design for the SHS. A SAM-like elevator actuator seals the chamber. Samples are introduced into and ejected from the chamber by a spoon-like manipulator. If a spacecraft carries a mass spectrometer to analyze evolved volatiles from soils and rocks, a vacuum chamber and sealing mechanism may already be equipped onboard that could be used for the KArLE experiment.

Potential targets for KArLE include dating the geologic evidence of past habitability, such as clay minerals, sulfates, and volcanic ash layers. We are currently using the laboratory breadboard to measure Mars and Moon analog materials, as well as characterizing and optimizing the performance of the components, as we pursue funding for construction and test of the flight concepts.

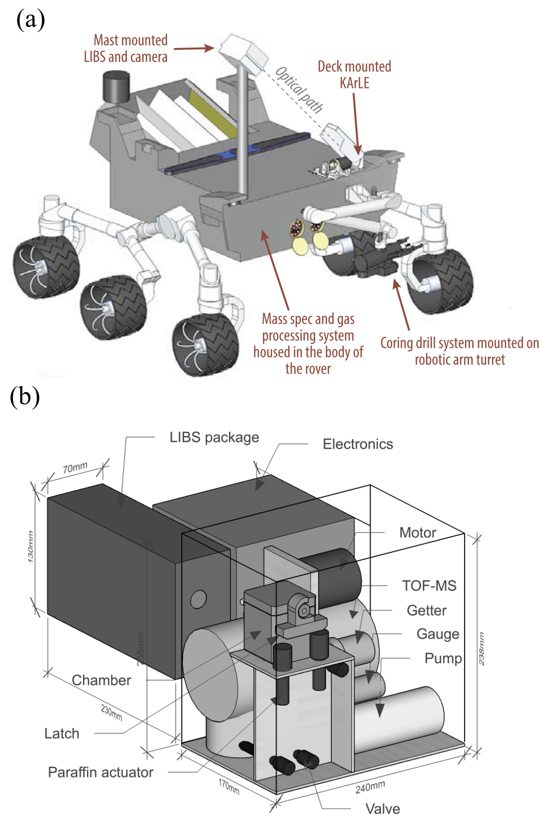

Fig. 2 Flight concepts of the KArLE instrument. (a) Curiosity-like concept (b) Package concept [10].

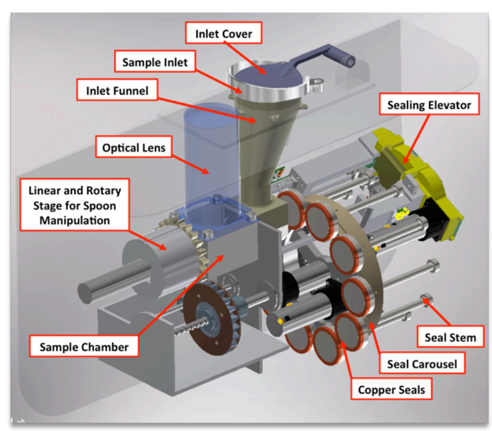

Fig. 3 Conceptual design for the KArLE SHS.

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